TEMPERATURE AND HEIGHT VARIABILITY IN THE MIDDLE AND UPPER STRATOSPHERE DURING 1964–1966 AS DETERMINED FROM CONSTANT PRESSURE CHARTS

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ABSTRACT

Daily 50- and 10-mb. height and temperature values for 3 yr. (1964–1966) are interpolated for specific locations from objectively analyzed charts. Time sections are constructed using these values, and the relationship of the time sections to the sequence of synoptic charts is discussed. Values from weekly 5-, and 2-, and 0.4-mb. synoptic analyses (1964–65) are used in making vertical comparisons with the 50- and 10-mb. values.

Monthly means and standard deviations of daily values from these monthly means are calculated and are compared with similar parameters derived directly from data. Comparisons of these statistical parameters are made for three geographical sections: 1) a north-south section near 80°W., 2) an east-west section across North America in middle latitudes, and 3) an east-west section across the Western Hemisphere at high latitudes. Vertical differences in variability and standard deviation are discussed.

1. INTRODUCTION

Since 1964, daily objective analyses of 100-, 50-, 30-, and 10-mb. stratospheric level charts have been produced at the National Meteorological Center (NMC). The analysis procedure includes a system of temperature and height adjustment in order to compensate for the solar and longwave radiation errors of the radiosonde instrument at high levels [5]. In addition, subjectively analyzed weekly synoptic charts for the 5-, 2-, and 0.4-mb. levels based on data gathered by meteorological rockets during 1964 and 1965 are prepared [6], [16], [17].

The purpose of this paper is to evaluate variability of height and temperature at several levels in the middle and upper stratosphere, utilizing these analyzed parameters. Determination of temperature and height variability, in addition to its intrinsic interest for research into the nature of the stratosphere, is of great importance for operations of high level supersonic aircraft, and for vehicles reentering the atmosphere.

For this study the 50- and 10-mb. levels were chosen for intensive investigation. The 50-mb. level (about 20 km.) is near the height proposed for supersonic jet operations and, as will be shown subsequently, exhibits interesting patterns of variability. The 10-mb. level (about 30 km.) is the highest level for which routine daily analysis is performed. Relatively small changes at this level often reflect greater changes taking place higher in the stratosphere.

To obtain the desired temperature and height values at the chosen locations from the daily objective analyses, a simple computer interpolation procedure is utilized. Monthly means of these parameters, standard deviations of daily values from these means, and time sections are also prepared by the computer. Selected time sections are presented in the following sections in order to illustrate latitudinal, longitudinal, and interlevel variability in the stratosphere.

2. DATA AND METHOD

In a statistical study of variability of meteorological parameters, one approach is to begin with observed values at a station and, after rejecting "wild" values through an objective test, calculate monthly or seasonal statistics for the station. This approach was utilized by the Air Weather Service [18] in the calculation of monthly means and standard deviations of height and temperature at stratospheric levels. Since in practice there will be many observation times for which the rawinsonde did not reach the level being studied, the number of observed values may be substantially less than those theoretically possible. (Summaries of rawinsonde performance prepared each quarter by the Weather Bureau [19] indicate that during 1964–66 few stations reached the 10-mb. level over 50 percent of the time during winter months.) Furthermore, the statistics will tend to be biased because the missing observations probably will occur on days unfavorable for aerological observations (e.g., strong or gusty surface winds, heavy icing, extremely cold tropopause, or strong winds aloft).

In the summaries of stratospheric parameters, such as those prepared for the IGY period([9], [11], [12]), seasonal means, standard deviations, and covariances calculated at stations are plotted on maps and isopleths are drawn. This assumes that values of these statistical quantities at different stations are strictly comparable, whereas such matters as variations in number of observations and differences in methods of adjustment of temperatures for radiation effects for different types of instruments would require modification of these assumptions.

In contrast to the above approach, the method followed in the present paper begins by performing once per day objective analysis of 1200 GMT station data. (A "merge" of data from the preceding and succeeding 0000 GMT data is used at stations where 1200 GMT data is missing.) In this procedure it should be emphasized that some observational

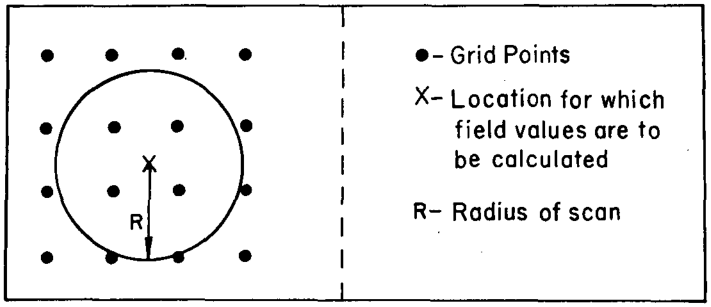

FIGURE 1.—Schematic of scan procedure.

data are rejected because of lack of hydrostatic consistency, large disagreements with observational values at nearby stations, or too great a departure from a "first guess" field based on persistence and upward regression. Additionally, in stratospheric objective analysis, wind data are used for geostrophic modification of the height fields [5]. (In other words, the final height field might more properly be called a field of geostrophic stream functions.) The resulting fields are plotted at every point on the NMC 1977-point Northern Hemisphere grid. The present statistical analysis begins with these plotted fields. Hence a value is available for every day at every grid point and, utilizing the interpolation procedure to be described below, at any chosen location.

Since station data are merged in time, rejected for failing various tests of spatial consistency, and in the case of heights, modified by introduction of geostrophic wind data, it would be improper to carry out such time series analysis procedures as calculation of lag autocorrelations or harmonic analysis. However in this study we are concerned with large-scale variations in height and temperature fields and do not attempt to draw any conclusions based on small day-to-day differences.

In deriving values for locations at grid points (e.g., the North Pole), values at the grid point were used without interpolation. However, most stations or locations used in this study fall between grid points. Hence a simple scheme was adopted for interpolating from grid point values to values at a particular location (fig. 1). All grid point values within a given scan radius R about the station location are utilized in making weighted interpolations according to the following formula:

$$X_{loc}=\frac{\sum_{i=1}^{n} W_i X_i}{\sum_{i=1}^{n} W_i}$$

where X_{loc} is the desired interpolated field value at the location chosen; X_i is the field value at the grid point i; W_i is a weighting function defined by the coordinates of the selected location and the grid points using the following formula:

$$W_i=R^2-d_i^2$$

where d_i is the distance from the location to grid point i, and n is the number of grid points within radius R of the location. For purposes of this study, empirical tests showed a value of $R=2$ grid lengths (539 km. at 60°N. on the NMC 1:30 million polar stereographic projection) to produce consistent results. Differences between the monthly means of values interpolated in this manner and values interpolated from monthly mean charts [15] were in no case greater than 0.1 percent.

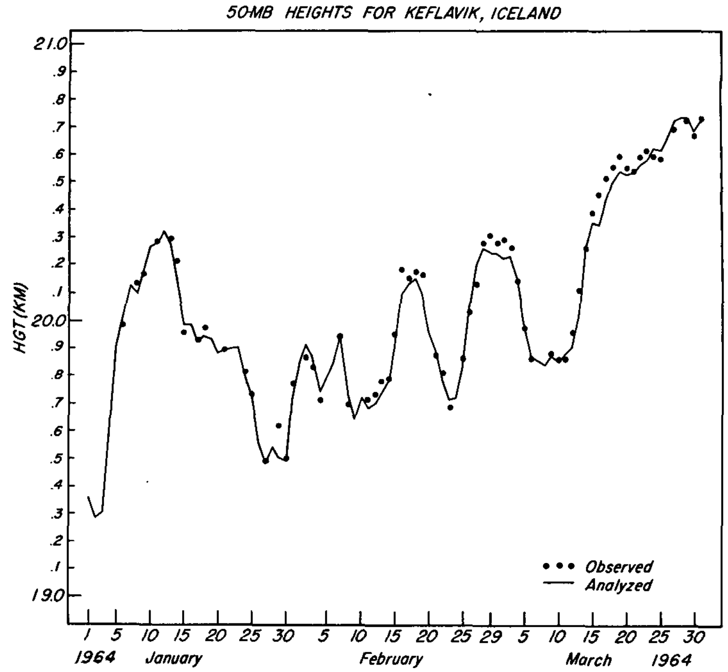

FIGURE 2.—Comparison of observed 1200 GMT 50-mb. heights (uncorrected) and analyzed 50-mb. height values at Keflavik, Iceland, January–March 1964.

3. COMPARISON OF STATISTICS FOR ANALYZED VALUES WITH STATISTICS FOR OBSERVED VALUES

In order to determine the validity of using analyzed charts as a basis for computing statistical parameters, several months of height and temperature values interpolated from analyzed charts were compared with reported rawinsonde data at several locations. An example of this may be seen in figure 2 in which 3 mo. of observed (uncorrected) 50-mb. heights at Keflavik, Iceland, are plotted together with the analysis values.

Monthly root-mean-square differences between the corrected observed values and the analyzed values were usually less than 60 m. for heights and 2°C. for temperatures. Since these values lie within the rejection limits of the objective analysis scheme [5], it seems reasonable to anticipate that the method followed in this paper would yield results in substantial agreement with those of other studies.

An Air Weather Service compilation [18] gives monthly means and standard deviations of observed data (corrected for solar radiation effects) at about 150 Northern Hemisphere rawinsonde stations for the period 1958–1962. Standard deviations were based on differences between daily temperatures and the 5-yr. monthly mean, so that larger standard deviations for high latitude stations in winter months are to be expected than in the present study in which standard deviations are calculated with

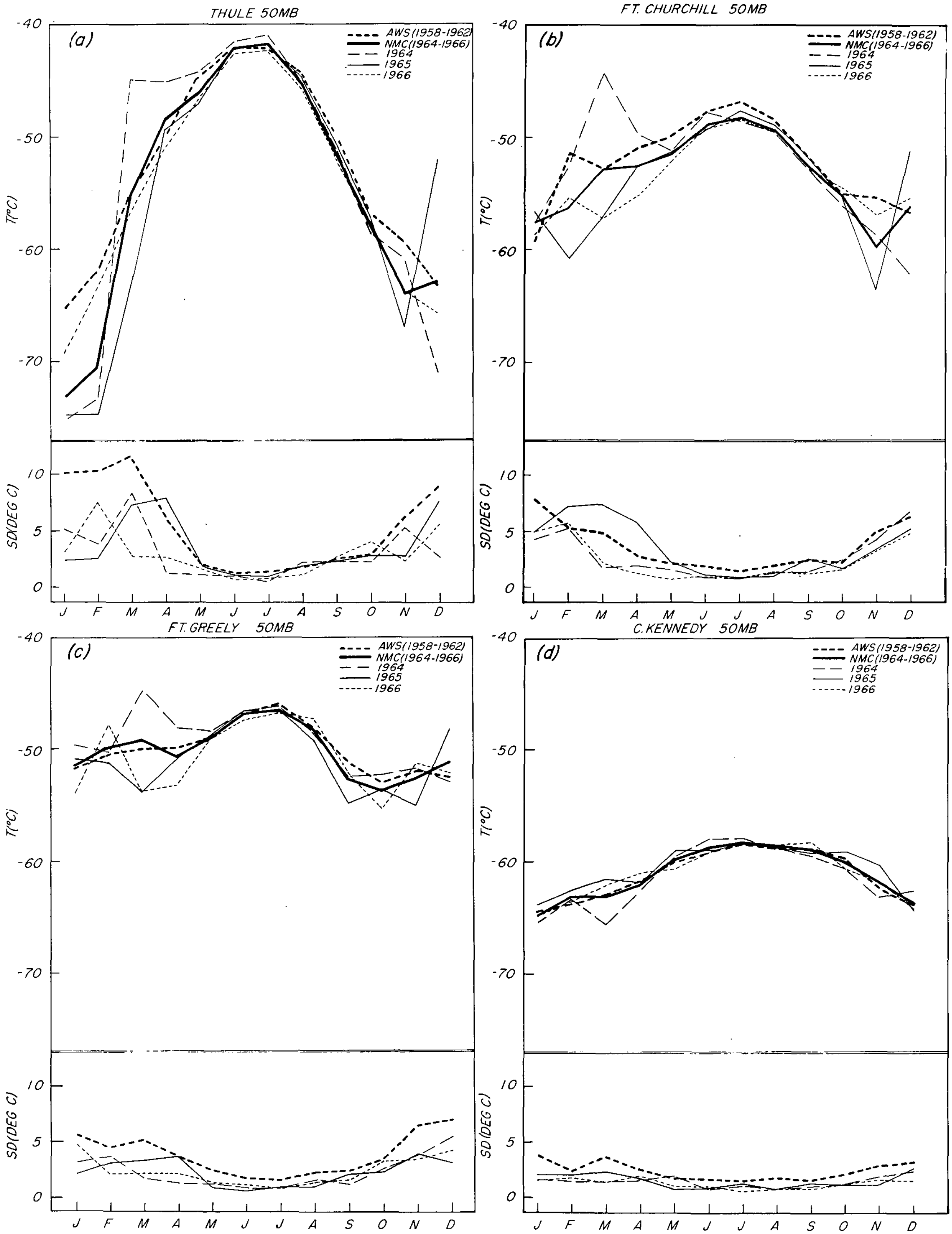

FIGURE 3.—Monthly means and standard deviations of 50-mb. temperatures (°C.). AWS values are from [18]. NMC values are from calculations in the present study. (a) Thule (77°N., 69°W.); (b) Churchill (59°N., 94°W.); (c) Fort Greely (64°N., 146°W.); (d) Cape Kennedy (28°N., 81°W.).

respect to the mean of each individual month; e.g., for January 1964, February 1964, and so on, up through December 1966.

Comparisons of 50-mb. temperature values of the present study with those given in the Air Weather Service data are shown in figure 3. In general the means for the two studies agree within 3°C. Owing to the different observational periods (1964–66 vs. 1958–62), some differences in the mean temperatures are to be expected. Moreover, in winter the means for individual months are typically more variable than the difference between the overall means for the two observational periods being compared.

For the present study, in areas where more data are available, greater day-to-day variations of analyzed values would be expected than in areas of less dense and less frequent data coverage, since in the latter case the analysis depends more heavily upon continuity from the preceding map and buildup from lower levels by regression equations [5]. The analysis scheme also includes smoothing of the height and temperature fields; therefore observed maxima and minima may be eliminated.

An error analysis study of the stratospheric level charts is currently being developed. Until this is completed the validity of statistics derived from these charts can rest only upon two subjective judgments: 1) These objectively analyzed charts compare favorably with daily charts hand-analyzed at the Free University of Berlin for the same period [13]. 2) The statistical parameters are in reasonable agreement with those calculated by other techniques.

4. POLAR TIME SECTION

The 10-mb. height and temperature values derived for the North Pole during January 1963–June 1967 are shown in figure 4a. The annual range of values at the Pole represents very nearly the maximum annual range of any Northern Hemisphere point. This is due to the monsoonal circulation of the stratosphere, in which a warm anticyclone is centered near the Pole in summertime, and a cold cyclone generally migrates about the Pole during winter. Thus the time section of polar values reflects the major annual variation of parameters which is associated with the annual variation of incoming solar radiation. Superimposed on this annual, nearly sinusoidal component are perturbations of varying scales.

During the summer, analyzed temperatures and heights are very consistent from year to year and the standard deviation of daily values from the monthly mean is very small. Maximum temperatures and heights occur in mid-July, after a slow and steady rise from the beginning of May. The relatively small amplitude of day-to-day temperature changes from May through August gives a graphical demonstration of the quiescent thermal pattern associated with the polar summer stratospheric easterlies.

After the midsummer maximum, the values decline steadily until a minimum is reached in January. During the autumn cooling period, small perturbations in this general trend may occur at varying times, but the rate of decline is nearly uniform from year to year.

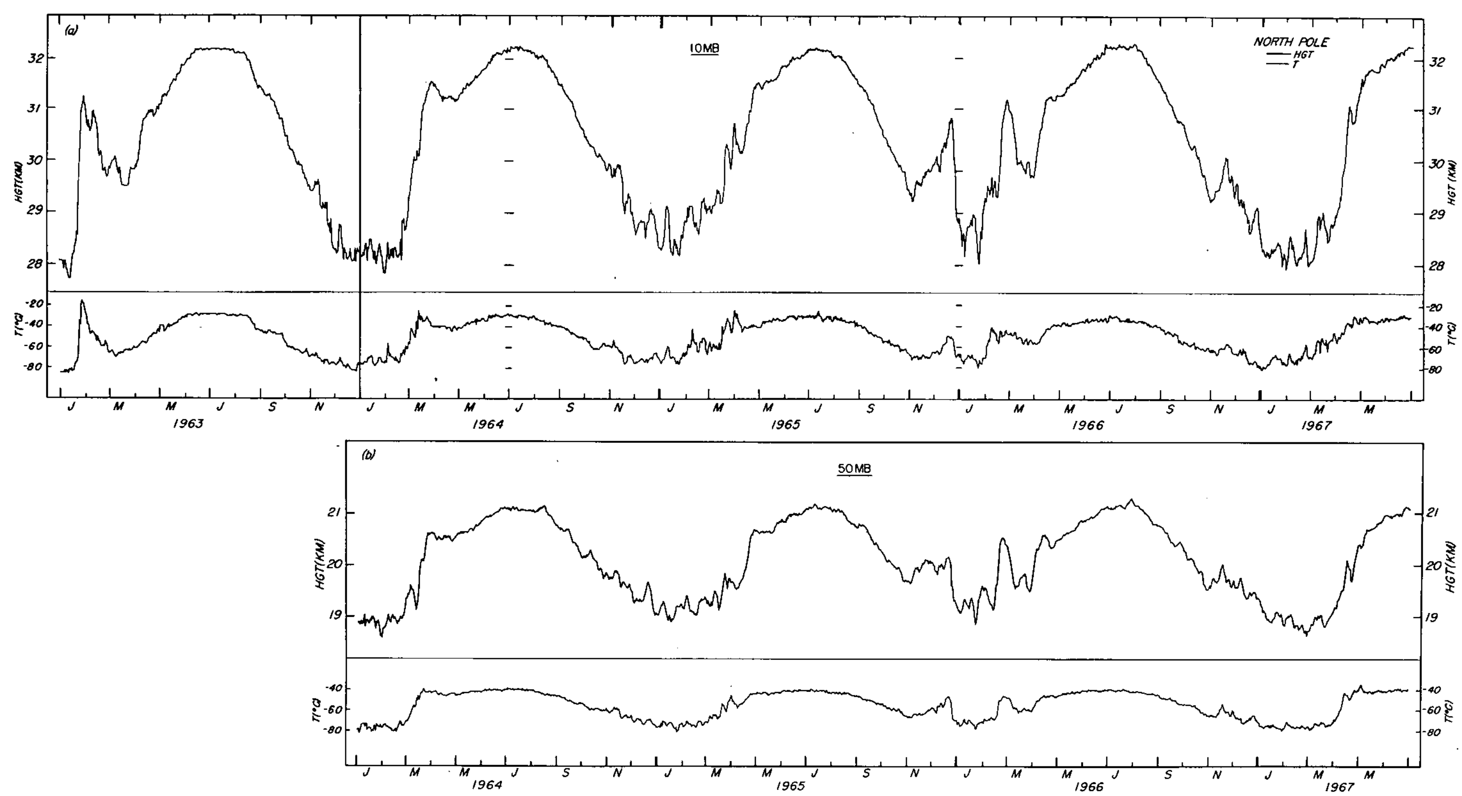

FIGURE 4.—Time sections of height and temperature at the North Pole. (a) 10-mb. level. 1963 data from Free University of Berlin Charts (1963). 1964–1967 data from NMC Upper Air Charts. (b) 50-mb. level. Data from NMC Upper Air Charts.

The winter storm period is the time when perturbations are evident in both the height and temperature traces. Some of these excursions from wintertime minima of temperature and height values occur in conjunction with a poleward extension of an area of relatively high temperature associated with the Aleutian anticyclone, and resulting displacement of the polar vortex.

Occasionally perturbations are associated with stratospheric warmings of either major or minor proportions. A major stratospheric warming occurred in January 1963 [4]. It should be pointed out that data for 1963 in figure 4a were extracted from subjectively analyzed charts [13]. The resulting curves appear to be consistent in both overall shape and extreme values attained when compared with those derived from the series of objectively analyzed charts begun in 1964 [3]. Minor differences in the appearance of the curves, especially in summer, are the result of differences in analysis and interpolation procedures for the two chart series.

A very sharp rise in height at the Pole on January 14, 1963, was associated with the establishment of an anticyclone after the complete breakdown of the wintertime polar vortex during a period of pronounced stratospheric warming. Temperatures reached values much higher than any maximum for the subsequent years. High temperatures persisted over the Pole until the end of January. Rapid cooling occurred in early February but the temperature did not again reach the cold prewarming winter level. The final warming began in late March, and the temperatures and heights rose, at first sharply, and then more gradually to the summertime peak.

In December 1965 and again in February 1966, large excursions of the 10-mb. height trace occurred, which approached in magnitude the height changes during the 1963 warming. The temperature rises, however, were only moderate, and the height increases were associated not with any large-scale circulation reversal, but only with movements of the polar vortex in conjunction with the movement of a well-developed anticyclone. Thus, similar traces in one or both parameters may result from grossly different synoptic events, and one should be wary of ascribing to any feature a unique cause solely on the basis of these time sections. The traces must be examined in light of all available information for the prevailing synoptic situation.

Year-to-year differences of height and temperature are commonly greatest in the period from January to April. The timing and graphical appearance of the spring warming varies, as can be seen from figure 4a. Moreover, a comparison of height and temperature values for the same date of different years may show striking differences. For example, there is a 2.7-km. difference between the 10-mb. heights on April 1 of 1964 and 1967, and a 15°C. difference in temperature.

An interesting feature noted previously [7] is the so-called spring thermal "overshooting." This phenomenon is characterized by a rapid rise in temperature during March to values higher than those of midsummer, and then a temporary decrease to lower values before the increase to the normal July maximum. On the North Pole time section (fig. 4a), the 10-mb. maximum temperature for 1964 is −25°C. reached on March 12, and for 1965 is −24°C. on April 1. However no overshoot is found at 50 mb. (fig. 4b). In addition, 1966 and 1967 values exhibit no spring overshoot at the Pole at either level. Relative maxima do occur during the spring, but temperatures do not exceed the summertime maximum.

Thus it is important to note that the spring overshoot does not occur at every location during every year. Locations near each other may have temperature patterns sufficiently different to yield a spring overshoot at one location and not at another. For example, compare the Thule (77°N., 69°W.) time section shown in figure 5 with the previously discussed time section for the North Pole. The available information indicates that when the spring overshoot occurs at both levels it is more noticeable at 10 mb. than it is at 50 mb.

5. CHURCHILL TIME SECTION

Figure 6 shows the 1964 and 1965 height and temperature traces for Churchill, Canada (59°N., 94°W.), at the two rawinsonde levels (daily values) and three rocketsonde levels (weekly values). Data for the rocketsonde levels were extracted from charts in [16] and [17]. The overall resemblance between the five height traces is to be expected since hydrostatic checks are used to maintain consistency in the rocket level synoptic analyses. The annual height range, however, is greatly amplified at successively higher levels, being about 2½ times as great at the 2-mb. level as at the 50-mb. level. On the other hand, the temperature range increases less rapidly, being less than twice as much at the 2-mb. level as at the 50-mb. level. The 0.4-mb. level is usually above the strato-

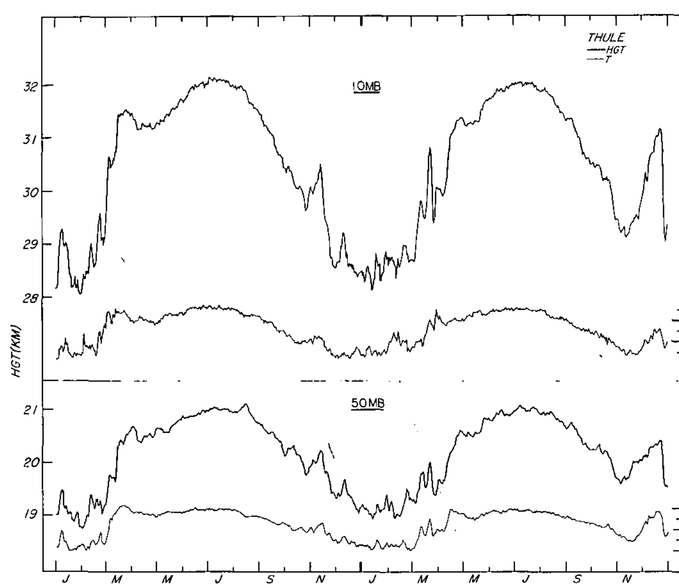

FIGURE 5.—Time sections of height and temperature Thule (77°N., 69°W.) 10-mb. and 50-mb. levels.

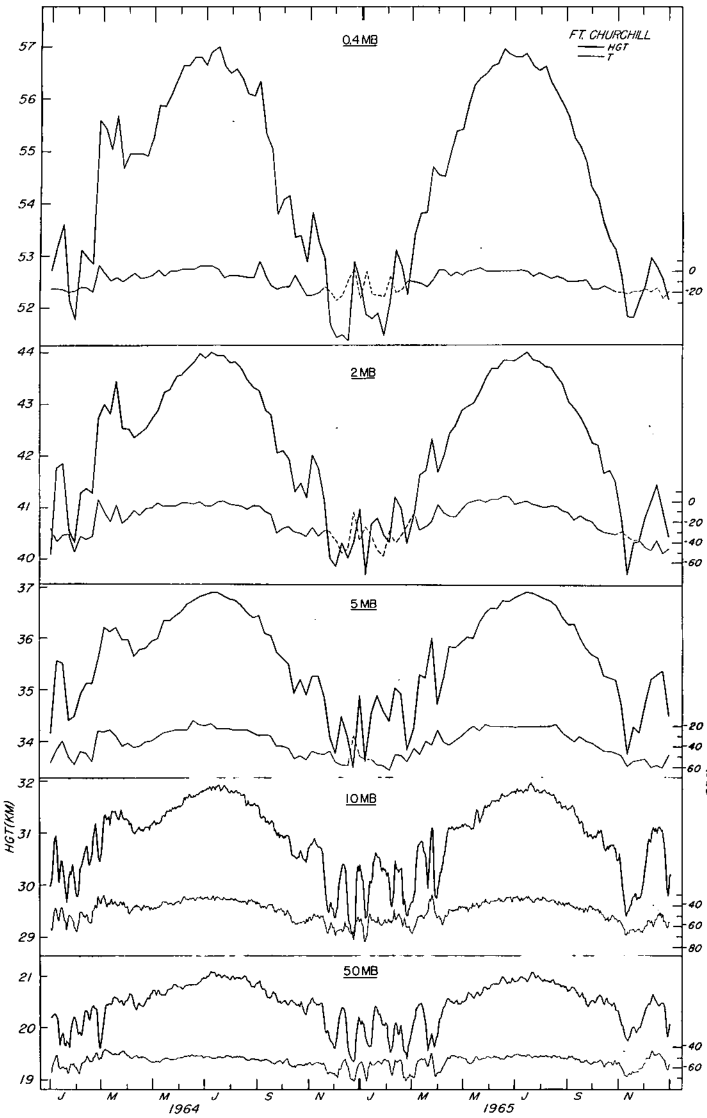

FIGURE 6.—Time sections of height and temperature at Churchill (59°N., 94°W.), 1964–1965. 50- and 10-mb. data from NMC Upper Air Charts. 5-, 2-, and 0.4-mb. level data from weekly rocket charts. (Dashed lines in temperature curves are for convenience in reading curves where overlapping occurs.)

pause at which a lapse rate reversal occurs. Hence a comparison of ranges at this level with ranges at lower levels would be misleading.

A careful comparison indicates significant differences in the time sections between the various levels. For example, at 50 and 10 mb. the lowest height values for the 2-yr. period are found near the close of 1964. This minimum is also found at 5 mb. on Dec. 23, 1964. However the minimum is not found on the two higher charts, and indeed at the 0.4-mb. level, the height reaches a maximum for the 2 winter mo. of December 1964 and January 1965. The reason for this may be seen in comparing the temperature time sections. At 50 mb., the temperature decreases to −72°C. on December 23, and at 10 mb. the minimum of −67°C. is reached on December 21. At 5, 2, and 0.4 mb., the temperatures are increasing. This

TABLE 1.—*Analyzed height decreases at Churchill, Manitoba, during Mar. 24–31, 1965, expressed as percentages of total height range (1964–1966)*

Level (mb.)	1964–1966 analyzed height range (geopotential meters)	Maximum decrease of analyzed height Mar. 24–31, 1965 (geopotential meters)	Maximum decrease as percent of range (percent)
0.4	5680	130	2.3
2	4350	640	14.7
5	3380	1280	37.9
10	2590	1363	57.6
50	1770	265	15.0

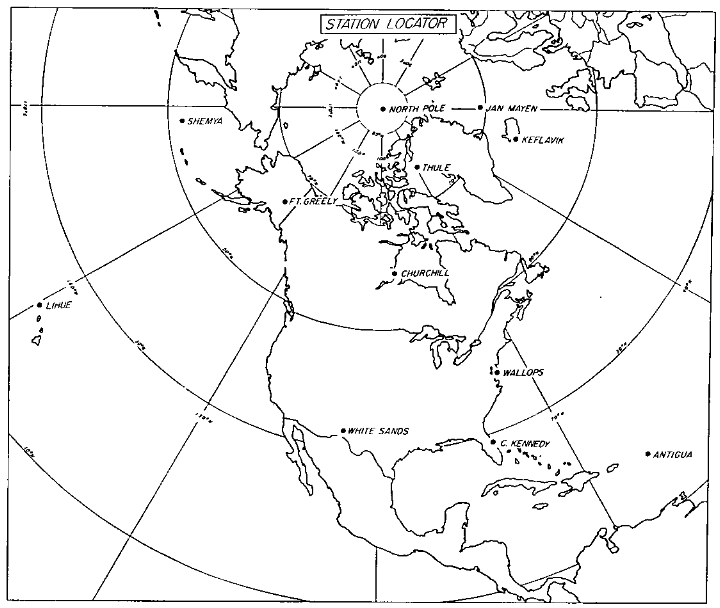

FIGURE 7.—Station locator chart.

causes an increase in thickness between the levels which results in the reversal of the height profiles. Similar interlevel variability may be seen at the beginning and end of January.

During the final week of March 1965 a spring overshoot of temperature occurs at the lower levels, with maximum temperatures for the year of −45°C. at the 50-mb. level and −29°C. at the 10-mb. level on March 24. This spring overshoot is not observed at the 5-, 2- or 0.4-mb. levels. Interlevel differences in the height changes are also noted. A decrease in height of about 250 m. is noted at the 50-mb. level. At the 10- and 5-mb. levels the decrease is over 1,000 m. At the 2- and 0.4-mb. levels the decreases are less significant, being 640 and 130 m. respectively. One way of evaluating the importance of these height differences is a comparison with the annual ranges of heights at the various levels given in table 1. It should again be emphasized that since no error analysis has been performed on the analysis systems, no quantitative conclusions can be drawn.

6. LATITUDINAL VARIABILITY OF HEIGHT AND TEMPERATURE

The series of stations, Antigua (17°N., 61°W.), Cape Kennedy (28°N., 81°W.), Wallops Island (38°N., 75°W.), Churchill (59°N., 94°W.), and Thule (77°N., 69°W.),

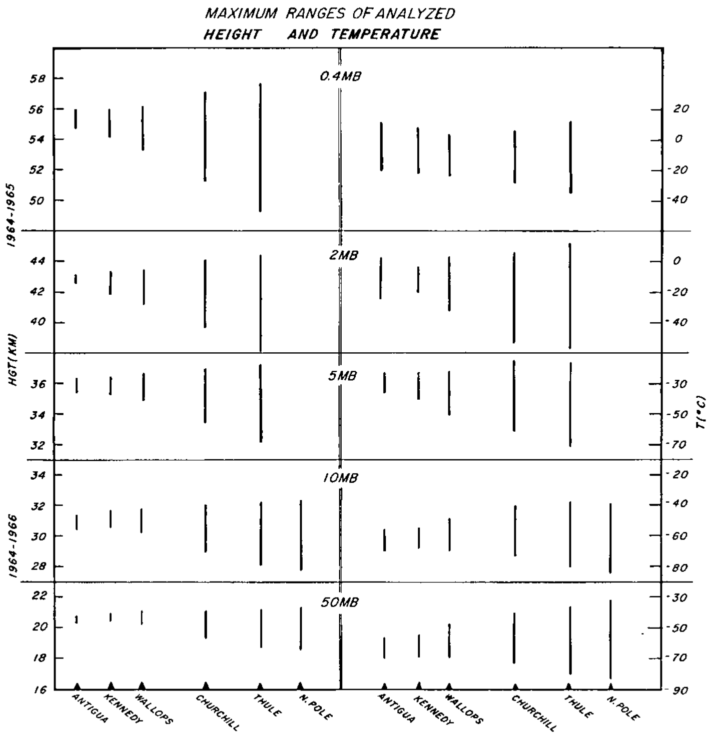

FIGURE 8.—Ranges of height and temperature at five levels along north-south cross section (50- and 10-mb. levels 1964–1966; 5-, 2-, and 0.4-mb. levels 1964–1965).

together with the North Pole (90°N.), may be used to construct vertical cross sections of temperature and height generally oriented north-south (see fig. 7 for station locations). Figure 8 shows the extreme analyzed values of height and temperature for each station at radiosonde and rocketsonde levels. The variation generally is greater at more northerly latitudes.

It should be noted that the increases with latitude especially in the annual ranges of 50- and 10-mb. height result mainly from decreases in minimum values during the winter. The maximum heights show little variation, especially at the 50-mb. level. This would suggest that the maximum mean virtual temperature from the surface to the 50-mb. level is very nearly independent of latitude, while the minimum mean virtual temperature is very largely a function of latitude.

A comparison of the variations of the standard deviations calculated from the analysis (fig. 9) indicates the regularity of summer height and temperature fields at all latitudes as well as an increasing variability with latitude during winter months. Minimum values are observed in July. The months of spring changeover (March and April) and of observed high stratospheric activity (November 1964, December 1965, and February 1966) are marked by the largest standard deviations.

Knowledge of the standard deviations of temperature at 50 mb. is important for proposed supersonic jet transport operations near this level. During the colder 5 mo. of the year, daily temperature values during a month will show standard deviations from the monthly mean as much as 8°C. at middle and high latitude stations, but less than 3°C. at low latitudes (fig. 9).

The 3-yr. (1964–1966) ranges of analyzed constant pressure height values increase with altitude and, in general, with latitude (fig. 10). Similarly, ranges of analyzed temperature values increase with height and latitude through the stratosphere (fig. 11). The smaller temperature variability found at 0.4 mb. is consistent with the observation of Nordberg et al. [10] that minimum latitudinal and seasonal temperature variability is found in the vicinity of 60–65 km. Figure 11 further indicates a minimum of temperature ranges at the 50-mb. level in the vicinity of 30°N. The increase in range towards the Equator should be noted. Not only does the range increase, but the 50-mb. temperature standard deviations at Antigua (17°N., 61°W.) are greater than at Cape Kennedy (28°N., 81°W.) for 20 out of 36 mo. of the present study. This increased variability at Antigua is found largely, although not exclusively, during the summer months.

An increase in variability near the Equator and corresponding decrease in subtropical latitudes near 50 mb. is also found in the cross sections of Smith et al. [14]. Since the mean height of the tropical tropopause is about 17 km., the increased variability at the 50-mb. level is probably associated with the variability in tropopause height. At about 30°N., a warm ridge line is usually present at the 50-mb. level resulting in less variability at that latitude than at the Equator.

7. LONGITUDINAL VARIABILITY OF HEIGHT AND TEMPERATURE

In figure 12, standard deviations of 50- and 10-mb. analyzed temperature are plotted for four middle latitude stations: Lihue (22°N., 159°W.), White Sands (32°N., 106°W.), Cape Kennedy (28°N., 81°W.), and Wallops (38°N., 75°W.). In general these locations show little difference in standard deviation. Several cases in which large standard deviations at one or two stations are found are discussed below.

Comparatively high values of 10-mb. temperature standard deviation (fig. 12a) for December 1964 at White Sands (4.8°C.) and Wallops (5.8°C.) result from the movement of troughs and ridges, which can be followed on the daily 10-mb. synoptic analyses [3]. At the beginning of December a warm ridge dominated the 10-mb. circulation over the southern United States. One large center was between Cape Hatteras and Bermuda and another was off the coast of lower California. By December 17 a cold trough extending southwards to Mexico from the polar cyclone had replaced the anticyclone as the dominant circulation feature over the area of interest. In the period between December 17 and 23 the polar vortex began to split, with one trough oriented southwestward to the eastern Pacific. A warm ridge extended westward from an anticyclone centered near Bermuda. During the next few days the anticyclone moved eastward towards the

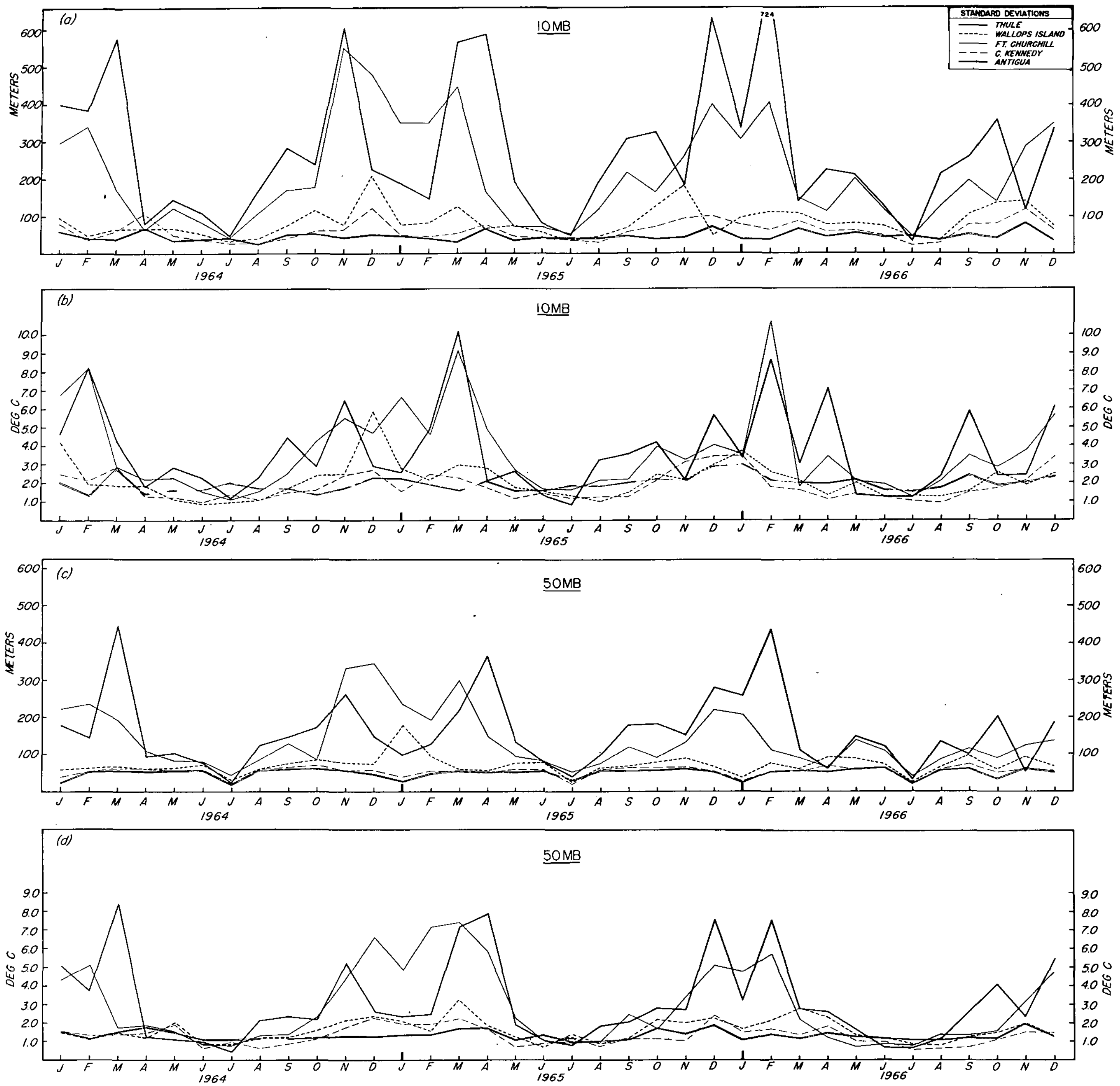

FIGURE 9.—Standard deviations at locations along north-south section for 1964–66: (a) 10-mb. height, (b) 10-mb. temperature, (c) 50-mb. height, (d) 50-mb. temperature.

Mediterranean and the center of the vortex returned to the Arctic region, with a cold trough over the United States.

This pulsating motion of the vortex and the accompanying changes in the temperature pattern provide an explanation of the unusually high values of the standard deviations of 10-mb. temperature at White Sands and Wallops for December 1964. At 50 mb. the two locations were in a cold trough for most of the month; therefore large standard deviations of temperature are not found (fig. 12b).

Two other prominent features of figure 12a are high standard deviations of 10-mb. temperature at Wallops in January 1964 and at White Sands in March 1965. During January 1964, the 10-mb. circulation over the United States was dominated by a warm ridge extending

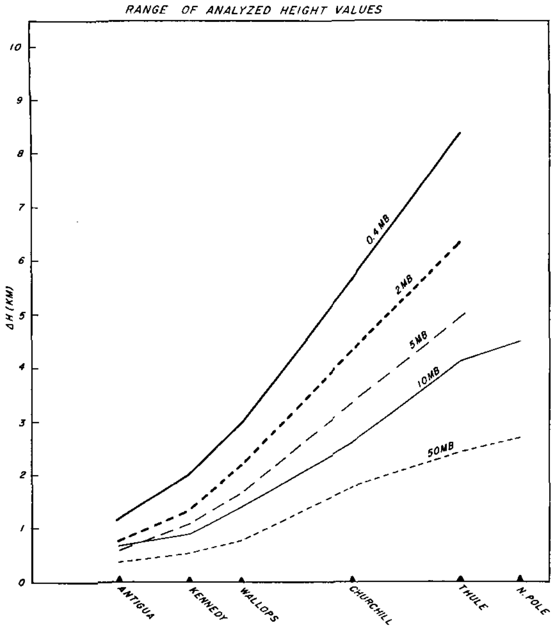

FIGURE 10.—Comparison of range of heights at different levels for stations along north-south section (50- and 10-mb. levels 1964–66; 5-, 2-, and 0.4-mb. levels 1964–65).

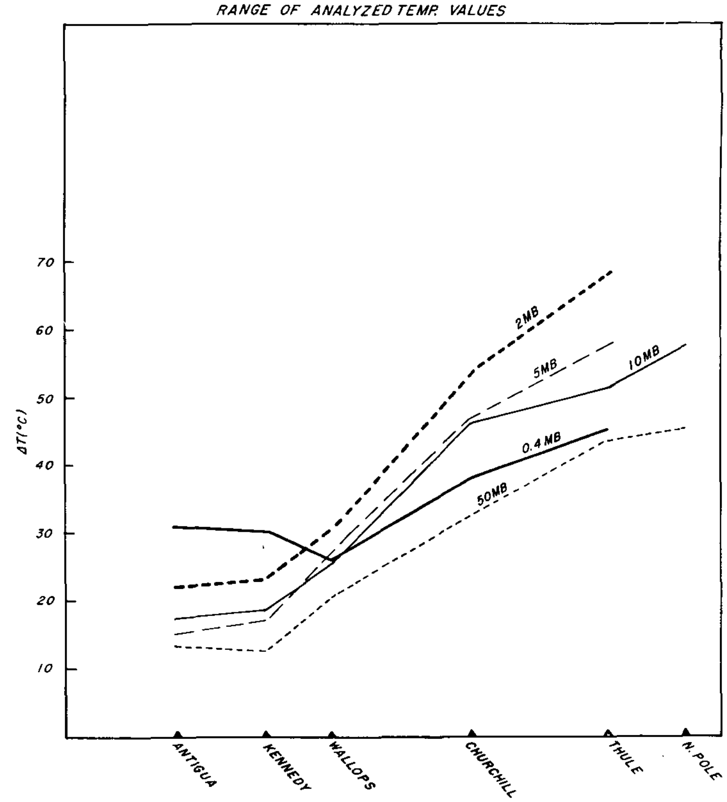

FIGURE 11.—Comparison of range of temperatures (1964–66) at different levels for stations along north-south section (50- and 10-mb. levels 1964–66; 5-, 2-, and 0.4-mb. levels 1964–65).

southeastward from the Aleutian anticyclone. Pulsations of this ridge as well as those of a trough in the western Atlantic were accompanied by 10-mb. temperature variations at Wallops Island. At White Sands, 10-mb. temperatures remained relatively high since the advance and retreat of the ridge generally had no effect on the area. Conversely, in March 1965, the 10-mb. circulation was marked by a number of migratory troughs and ridges. Wallops remained in a region dominated by a cold trough for most of the month, while the temperature over White Sands changed markedly with the passage of a number of cyclones and anticyclones.

Although little east-west variation is evident at middle latitudes, the differences become noticeable at the higher latitudes. The effect of the warm Aleutian anticyclone ([1], [7]) can be seen in a comparison of differences in ranges of analyzed height and temperature at different longitudes. The series of stations, Shemya (53°N., 174°E.), Fort Greely (64°N., 146°W.), Churchill (59°N., 94°W.), Thule (77°N., 69°W.), Keflavik (64°N., 23°W.), Jan Mayen (71°N., 9°W.), may be used to construct cross sections along an east-west profile across high latitudes (see fig. 7 for station locations).

Figure 13 shows the ranges of temperature and height at the above stations for 1964–66. The smallest range is at Shemya, located in the area affected by the Aleutian anticyclone which is nearly stationary for long periods during the winter. On the other hand, the greatest ranges are found at Churchill, Keflavik, and Jan Mayen; these locations are dominated by the migratory polar vortex in winter.

Although the relative storminess at high latitudes causes great fluctuations in standard deviations at all longitudes, temperature and height standard deviations generally increase from west to east (fig. 14). Especially during winter months, Shemya and Fort Greely usually have lower monthly values of standard deviations than Churchill, Thule, and Keflavik.

Previous summaries of stratospheric parameters include those prepared for 1957–60 by Smith et al. [14], and those for the IGY period (1957–58) by Murakami [9] and Peng [11], [12]. These authors include charts of temperature and height standard deviations.

Their values are not strictly comparable with those of the present study, since they utilize a necessarily sparser network of stations, and calculate standard deviations of observations from a 3-mo. mean. Also their observations have not been adjusted for radiational effects. These differences may explain why the increases in variability from the Aleutian anticyclone east to the vicinity of Iceland are not as apparent in most of their charts as in the graphs of the present study.

8. VERTICAL DIFFERENCES IN STANDARD DEVIATIONS

At middle and high latitude stations, standard deviations of temperature and height tend to be greater at the 10-mb. level than at the 50-mb. level (compare fig. 14b with fig. 14d). A study of relative changes indicates that the summer period of low temperature variability for

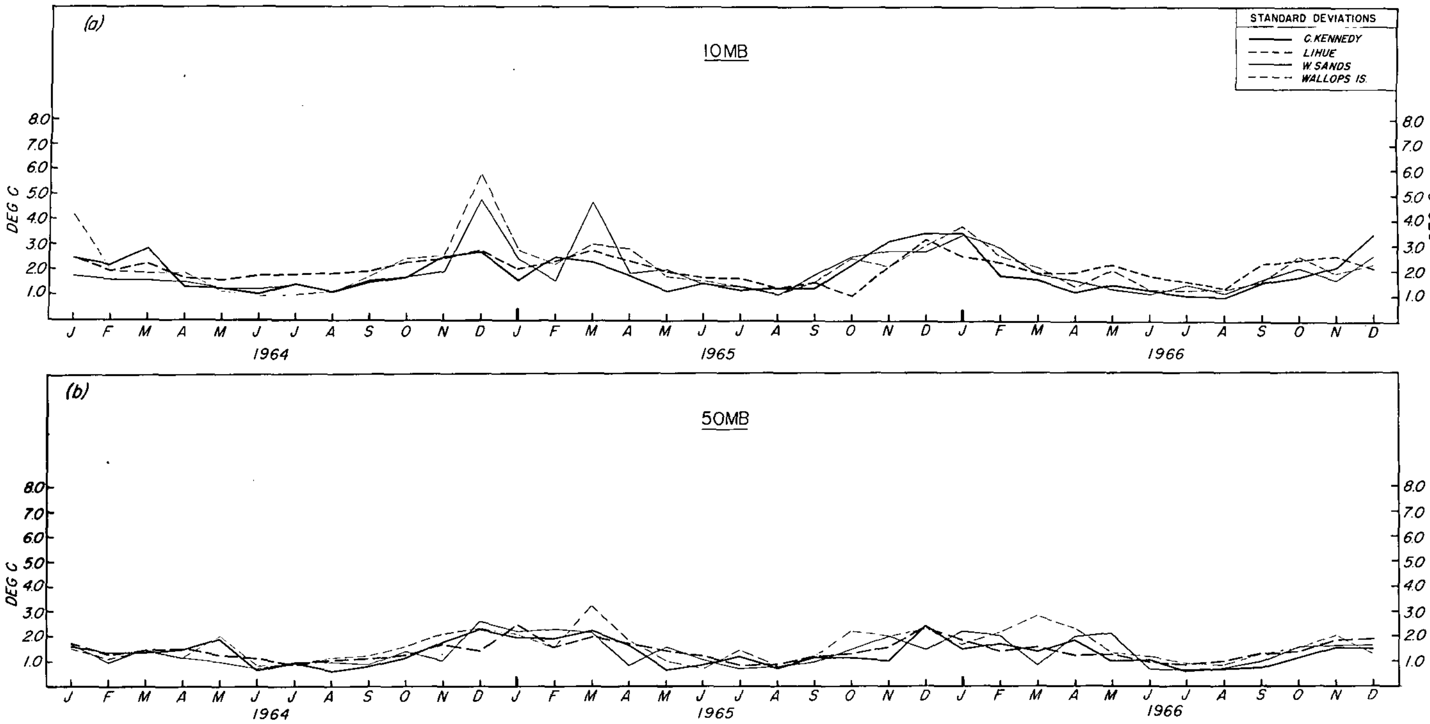

FIGURE 12.—Standard deviation of temperature for stations along midlatitude east-west section (1964–66). (a) 10 mb., (b) 50 mb.

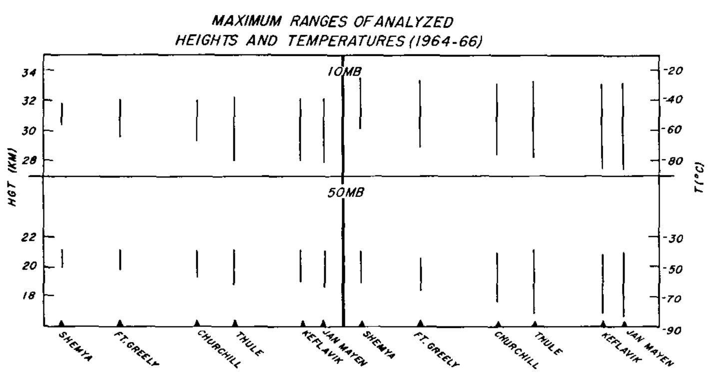

FIGURE 13.—Ranges of height and temperature at 50- and 10-mb. levels at stations along high latitude east-west section (1964–66).

most stations begins in April 1964 and May 1965 at both levels. In the spring of 1966, low variability begins in March at the 50-mb. level, but not until May at the 10-mb. level.

The autumnal breakdown of stable thermal patterns is observed to occur earlier at the 10-mb. level (fig. 14b) than at the 50-mb. level (fig. 14d). At the 10-mb. level in 1964 the temperature standard deviation rise begins at Thule in September; and at other stations in October. In 1965 the sharp rise from summer minimum standard deviations begins in August at most of the stations. Rises at the 50-mb. level begin generally in October of 1964 and 1965 and September 1966.

9. CONCLUSIONS

This study using analyzed parameters from stratospheric charts leads to the following conclusions:

1) The analyzed values of the height and temperature fields are comparable with observed values and can be used as data for simple statistical calculations. Monthly means and standard deviations of daily values from these monthly means are in reasonable agreement with values of these parameters derived from observational data.

2) A time section of North Pole 50- and 10-mb. height and temperature shows features identifiable with stratospheric warmings of major and minor proportions, as well as with other perturbations not studied or identified in this paper.

3) The "spring thermal overshoot" is found to occur irregularly; temperatures greater than midsummer may occur at one level and not at another or at one station and not at another nearby. This is accompanied by great year-to-year variability in the springtime height of constant pressure surfaces. The months of spring changeover (March and April) and of high stratospheric activity during the winter storm period are marked by the largest standard deviations. The autumn and summer months exhibit considerably less variability.

4) Time sections of the height of constant pressure surfaces show a resemblance from 10- to 0.4-mb. level. Some differences at the various levels can be explained in terms of the variations in analyzed temperature fields at these levels and the implied mean temperature changes.

5) In a north-south cross section for 17°N.–90°N. near the East Coast of the United States, variability of height and temperature fields is a minimum near 30°N. and increases towards both the Pole and the Equator. The variabilities increase with altitude to the vicinity of the stratopause, above which the temperature variability begins to decrease. Increasing height ranges at higher latitude locations are due to lower heights near the centers of troughs and cyclones passing the location. Maximum height of a constant pressure surface is very nearly independent of latitude.

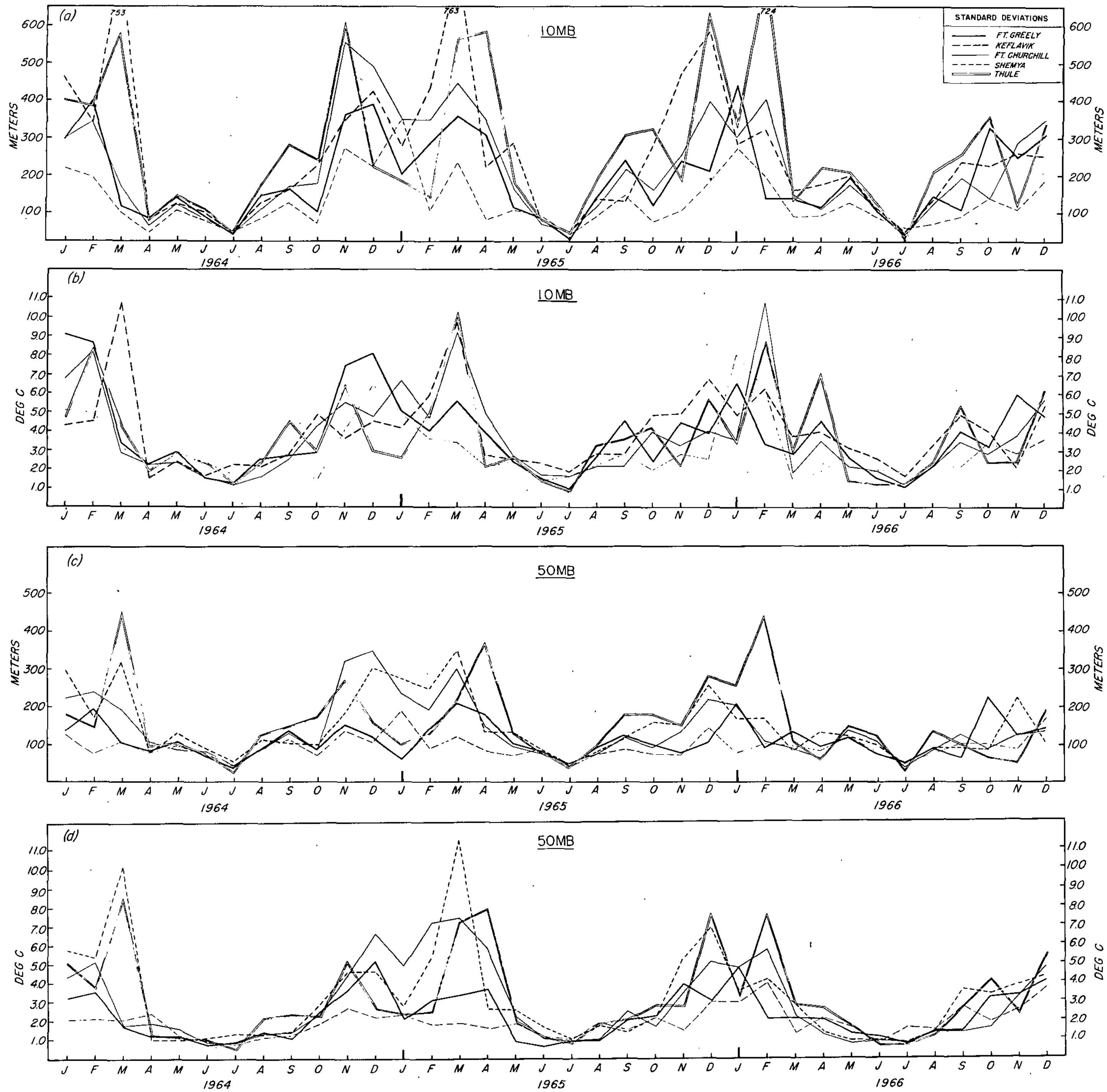

FIGURE 14.—Standard deviations at stations along high latitude east-west section (1964–66): (a) 10-mb. height, (b) 10-mb. temperature, (c) 50-mb. height, (d) 50-mb. temperature.

Absolute temperature variations with height begin to decrease between 2 and 0.4 mb., and the range of temperature variation at the higher level is noticeably less.

6) High values of thermal variability during certain months as indicated by high values of temperature standard deviation can be explained by relatively few large departures linked with synoptic systems apparent on the daily analyzed charts.

7) An east-west cross section of height and temperature variability across the western half of the Northern Hemisphere near the Arctic Circle shows greater ranges and variabilities near Greenland and eastern Canada than in the western portion. This reflects the influence of the warm stratospheric Aleutian anticyclone.

8) Thermal patterns reached summer minima of standard deviation earlier at the 50-mb. level than at the 10-mb. level in one summer out of the three studied; in the others no difference can be noted. The autumnal activity of the thermal fields is noted earlier at the 10-mb. level than at the 50-mb. level in all three autumns studied.

10. FURTHER AREAS OF STUDY

It should be emphasized that values found in this study are derived for the years 1964–1966. The comparisons made in the text with values for other periods indicate that this is too short a period for the results to provide climatological information. Such phenomena as the quasi-biennial oscillation may additionally complicate the picture. Moreover, the large variabilities associated with a major stratospheric warming such as that of January 1963 are not included in these statistical results.

Furthermore, the meridional section chosen for study is near the East Coast of the United States. There is no reason to expect that similar statistics would be found for a cross section over the Eastern Hemisphere or in the Pacific area. Indeed the east-west variability found at high latitudes indicates that a north-south section in the vicinity of the Aleutian anticyclone would necessarily be quite different from the one shown in this paper.

A variety of areas for the further investigation are possible using the techniques of this study:

1) Cross section studies and statistical calculations along other latitudes and longitudes, especially in areas of sparse data.

2) Analysis of specific periods of stratospheric activity (e.g. February 1966 [20]).

3) An extension from the directly analyzed parameters (height and temperature) to derived quantities (vorticity [2], temperature gradient, geostrophic wind, etc.) and comparison of these with other parameters of interest (e.g., clear air turbulence [8]).

4) Study of the relationship of stratospheric temperature and wind variability to the quasi-biennial cycle.

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